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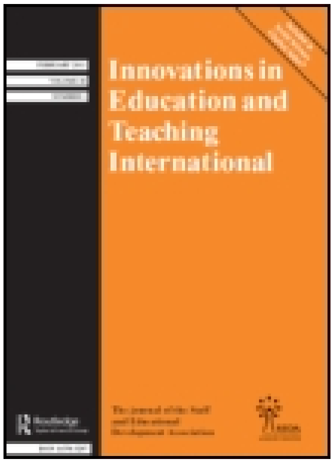

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STRATEGY, COMPETENCE AND CONVERSATION AS DETERMINANTS OF LEARNING

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STRATEGY, COMPETENCE AND CONVERSATION AS DETERMINANTS OF LEARNING

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Abstract: The paper reviews some practical consequences of a recent theory of learning and teaching. In the light of these, it is contended that attention should be given to the student's learning and performance strategies; that the strategies employed in a teaching system should be matched to the student's underlying competence to execute them and that an effective teaching system should be conversationally structured insofar as appropriately matched strategies can only be determined in an active (though possibly mechanised) dialogue between the teacher and the student. These points of view are supported by a series of experiments on relation learning (fully reported elsewhere) that have been carried out in the author's laboratory.

INTRODUCTION

LEARNING depends upon the strategies used by a student in order to direct his attention and partition the educational goal into subgoals that are separately addressed. At one extreme, these strategies may stem from the student himself; they are *learning* strategies which he brings to bear upon an otherwise unstructured situation. At the other extreme, the strategies may be imposed upon the student as *teaching* strategies by a program, a teaching device, or a training routine. Many real situations lie between these extremes. One of them is a tutorial conversation in which methods of learning are open to discussion and in which the strategy is selected as a result of a compromise between the student and the teacher.

Though strategies are important, it is also necessary to consider the student's competence in executing strategies of a given class. For example, an individual student may be good at " seeing things as parts of a whole " or, conversely, he may have a special aptitude for " stringing subproblems into sequences," which (on resolution) lead to the solution of a large problem. There are, of course, many other types of competence; for example, competence demarcated along the visual/verbal dimension or competence determined by the relative efficiency of " short term " and " working " memory.

Now, certain types of strategy call for certain types of competence. For instance, some strategies can best be (in the limit, can only be) executed by the " holist " student of our example, whereas the execution of other strategies rests upon a " serialist " competence. By hypothesis, effective learning takes place if, and only if, the individually selected (learning or teaching) strategy is matched to the student's existing competence.

Since students are generally unaware of their competence, a free learning student is unlikely to learn well. The combinatorial problem of mating the strategy choice to a (largely unknown) competence profile is considerable on its own, but there are also specific factors which militate against effective learning by positively encouraging *mismatch.* One of the most important is " cognitive fixity," a tendency to adhere to an originally selected strategy even in the face of evidence showing it to be inappropriate.

The position is somewhat different if a teacher or a teaching program is introduced into the situation; so far as he (it) is obeyed, the teacher (program or machine) usurps the role of the *student's internal attention directing* mechanism and guides his learning according to a teaching strategy. In the simplest case, the teaching system is designed on the basis of a single strategy. This is a provident design provided there are grounds for holding that a single strategy is, in some sense, apposite; for example, " there is only one possible strategy " (rarely, if ever, true), " one strategy is better than the others, *i.e.* there is an optimal strategy " (true in a few cases; note, for instance, Matheson (1964) on list learning) or " one strategy is far more economically administered than the others, and individual differences have little influence upon the rate or effectiveness of learning " (quite often true and generally used to justify an instructional program that is neither branching nor adaptive).

Generally, however, such grounds for uniqueness do not exist and, in this case, the design of an effective teaching system must be founded upon a class of strategies. Sometimes one member of this class can be chosen for use on a given occasion with a given individual by an adaptive procedure that employs feedback from performance measures and the like. If so, the most important process involved in reaching such a decision is a matching process whereby the student's competence is weighed up and a strategy is selected to suit it. More often the set of strategies is not given *a priori* and its members must be determined by a (human or mechanised) conversation of the sort alluded to in the second paragraph. In practice, also, there are other factors to do with the regulation of uncertainty and the student's motivation which often dictate the use of a conversational teaching system. But, within the conversational format, there must still be a tendency, even an authority, to maintain matching. The compromise solutions accepted by the teaching system must be those that engender matching even if they do not completely secure it.

The first part of the paper develops the notions of strategy, competence and of cognitive fixity at a quite general level. The second part summarises the results from a series of experiments on conversational and free learning, recently carried out in my own laboratory. Although the experimental task is miniature, it is argued that these results are relevant to a large field of teaching and that they support the thesis developed in the first part of the paper.

1. GENERAL LEARNING SITUATIONS

The following sections discuss the notions of strategy, matching and cognitive fixity in greater detail; though still with reference to learning in general (rather than the skill involved in my own experiments). Amongst other things it is necessary to distinguish between *performance* strategies concerned with the execution of a skill and the *learning* (or teaching) strategies that build up performance strategies. These ideas are developed at a theoretical level in other publications (Pask 1965 a and b, 1968a, 1969a, 1969b). For the present purpose, a thoroughgoing theoretical discussion can be avoided and the various entities or processes are defined ostensively by reference to their occurrence in well-known tasks.

Performance strategies

Performance strategies have been studied with respect to a great many tasks. In the context of a perceptual motor skill, such as typewriting or vehicle control, the performance strategy is an operational or imperative interpretation of the hierarchical organisation in which subskills, associated with the achievement of subgoals, are integrated into the skill as a whole. The notion of skill organisation is nowadays so ubiquitous that the issue requires no detailed discussion (for the strategies involved in even the simplest of tasks, compensatory tracking, see for example Pew (1966), Gaines (1968), Angel and Bekey (1968) and Pask *et al.* (1968)). It should be noted that skill organisations differ appreciably between individuals although detailed scrutiny reveals that the idiosyncratic performance strategies cluster round no more than four or five basic types.

Over a wide range of more intellectual tasks, performance strategies are manifest in the hierarchical organisation of problem solving procedures. This is clear, for example, in the protocols produced by Newell, Shaw and Simon's (1962) subjects or Reitman's (1965) subjects (who addressed themselves to logical demonstration; in a weak sense " theorem proving "). More objectively, Gagné (1962) has exhibited an hierarchical structure of items of knowledge, which is a prerequisite for carrying out a " number series completion " task. This structure constitutes a problem subproblem (or goal subgoal) hierarchy and, taken operationally, it generates a performance strategy.

Another instance is provided by Bruner, Goodenow and Austin's (1956) work on concept acquisition. Their subjects adopted several strategies which were externalised, in the conditions of the experiment, as stretches of behaviour. Any strategy is a procedure for setting up and testing hypotheses about an unknown conjunctive category of the graphical exemplars in a finite universe of discourse, which is described in terms of four attributes (of the form " shape of figure " or " colour of figure "). Two main conditions were employed, *receptive* and *selective*. In the receptive condition, the experimenter has a conceptual category in mind (unknown to the subject) and he presents the subject with a sequence of exemplars (figures characterised by certain values of the descriptive attributes) furnishing, for each one, the information that it does or does not belong to the unknown class. From time to time, the subject submits an hypothesis about the unknown class and, if necessary, is corrected. In the selective condition the subject (rather than the experimenter) has control over the evidence in so far as he is able to select exemplars which are submitted for tests of class membership. Subjects run in the receptive condition generally adopted one of two strategies, " holist " and " partist "; those run in the selective condition adopted one of four: " successive scanning," " part scanning," " focusing " and " focus gambling." The nature of these strategies is detailed in the original work; the immediately important point is that though different individuals set about solving the problem in different ways, the variation is, in practice, quite limited. Although repeated performance of the task engenders a few novel strategies, most, if not all, of these are mixes of the basic ingredients noted above (Lewis and Pask, 1964).

As a final example, strategies occur at a level of cognitive activity which is generally deemed innovative or, at least, insightful. These strategies have been studied by Elshout (1969), using the apparatus test as the experimental task (the subject is asked to provide two improved versions of a given piece of " apparatus "; to cite one of the author's examples, a " chair "). Two strategies were distinguished: " successive transformation " and " locating problems." Using the first, the subject reduces the problem of finding an improvement into (1) the subproblem of finding some property of the apparatus that needs improvement (usually culled from his own experience), (2) the subproblem of transforming this property to yield an improved apparatus. Using the locating problems strategy, the subject (1) considers the set of properties of the given apparatus and selects one (*e.g.* the chair " *stands* on the floor "), (2) replaces this by an imagined related property (another value of the same attribute, *e.g.* the chair " *lies* on the floor "), (3) finds a problem encountered in connection with the original apparatus (a chair that *stands* on the floor) that would be solved if the apparatus were modified (*i.e.* if chairs in fact, *lay* on the floor), (4) solves this problem by finding an innovation (some sort of collapsible chair, *e.g.* a deckchair) that can *both* lie on and stand on the floor.

Broadly, therefore, performance strategies characterise a very wide spectrum of the mental processes, which can be captured and objectified in laboratory studies. There is, of course, abundant discursive evidence that strategies are involved in *all* sorts of cognition and recollection (for example, in answering questions about a certain period of history or a certain field of mathematics).

Learning strategies

Given a realistically sized task (and assuming that he cannot already perform it), a student is unable to generate the required performance strategy all at once. Instead, he directs his attention to various facets or subtasks and musters subroutines that build up a performance strategy bit by bit. The process is carried out according to a learning strategy which, in the free learning subject, may be innate or acquired and which, for the student, is imposed externally by a teacher or a teaching system.

I maintain that a learning strategy is comparable in kind with a performance strategy. Each sort of strategy entails breaking goals into subgoals and applying mental subroutines to achieve the subgoals concerned. The necessary difference between learning strategies and performance strategies is in the domain upon which they operate. Whereas the performance strategy solves problems posed by states of the (usually symbolic) environment, the learning strategy solves the problems posed (in the context of a goal like " learn to solve apparatus test problems ") by deficiencies in the current repertoire of relevant performance strategies; the solutions produced by a learning strategy are performance strategies.

Sometimes there seems to be a confusion between learning and performance strategies but the ambiguity disappears if the task is well defined and the extent to which learning is externalised in behaviour is fully stipulated. For example, are the Bruner, Goodenow and Austin (1956) concept acquisition strategies of one sort or the other? Well, it depends. If, as pictured in the last section, the subject is solving a problem, posed by the experimenter (" describe the unknown class ") then the strategy is a performance strategy (as we maintained). But the concept acquired in the process is not just a class description; it may be regarded as a procedure (in fact, just another name for " performance strategy ") designed to recognise members of this class. If so, then the Bruner, Goodenow and Austin strategies are learning strategies and the conduct of the experiment externalises a learning process. For instance, in some of the small group experiments carried out in my own laboratory (Lewis and Pask, 1964), subjects were required to *use* the concepts they attained; in this context the Bruner, Goodenow and Austin strategies are unequivocally learning strategies. Likewise, in Hunt, Marin and Stone's (1966) simulation of this situation, the " artificial intelligence " program representing the student uses (extended versions of) the Bruner, Goodenow and Austin strategies as the learning strategy whereby it constructs a concept of the form " performance strategy."

So far as the other examples of the last section are concerned, there is little room for doubt about a reasonable interpretation. Without diffidence, we can assign the action of a typist in tackling subsets on the keyboard separately, to the class of a learning strategy which builds up the motor programs (performance strategies) required in order to perform the skill. Nor is it too difficult to trace the modification of these programs as the skill develops (Pask, Scott, Mallen *et al.*, 1969). Again, we have no hesitation in distinguishing the organised acquisition or inculcation of the " successive transformation " or the " locating problems " strategy from the performance strategy itself.

In conclusion, the first aspect of a learning strategy is a contingent plan (*i.e.* the plan may depend upon indices of success or the like) for selecting fields of attention. Thereby, the student directs his attention to different parts of the task, to different subgoals or subproblems. In this definition, the field of attention is the domain of some performance strategy and it may either be part of the external environment or an internal representation of it; the latter possibility is pertinent when learning involves rumination, covert rehearsal and other processes which have no direct behavioural correlates. (As a matter of fact, we shall be primarily concerned with situations in which precautions have been taken to ensure that the domain in question *is* related to the external environment so that attention directing can be objectively scrutinised. But this condition is not required by the basic statement.) Generally, the performance strategies, whose domains are selected by a learning strategy, are incomplete or even embryonic entities (figuratively, " boxes waiting to be filled in "). If so, then the learning strategy musters operations that act upon the form of the performance strategy; operations that remedy its defects or, in the limit, that construct it. This is the second aspect of a learning strategy. So, by way of a summary, a learning strategy is first of all a contingent plan for selecting performance strategy domains (fields of attention) and secondly a plan for building these strategies or for repairing them.

Individual competence and strategic effectiveness

Learning strategies call for the execution of mental subroutines which are relatively permanent features of the mind; for example, the subroutines involved in abstraction, in concatenation or " stringing together," in substitution (of one operation by another) and so on. By the same token, performance strategies make use of several relatively permanent subroutines, notably those that organise the short term and working *storage* of the brain into coherent *memory* systems (as shown, for example, by Atkinson and Shiffrin, 1967). There is ample evidence that the efficiency of different subroutines, at either level, varies a great deal from person to person; perhaps, also, from day to day. I shall call the distribution of efficiency evaluations over the subroutines the subject's competence (or competence profile).

A subject's competence is determined by presenting him with paradigm problems of a given type and finding how efficiently he solves them. There is nothing new in this. Multiple aptitude and ability tests provide the requisite data so far as performance strategies are concerned and since it is maintained that there is no necessary distinction in kind (only in domain) between performance and learning strategies, this data is just as good in respect to the " higher level " operations. Nor is the interpretation of ability test results in terms of a competence profile altogether original. Guilford's (1960) " Structure of " Intellect " model is proposed in a similar spirit. But Guilford as an essentially descriptive approach; he maintains that mental factors, isolated by the factor analysis of test batteries, can be categorised and refined in several ways to yield the familiar three-dimensional figure with operations (evaluation, convergent thinking, divergent thinking, memory, cognition) along one side, with contents (figural, symbolic, semantic) along the next, and with products (units, classes, relations, systems and implications) along the last. It is possible to obtain specific estimates of differential competence in respect to many of the 90 cells so distinguished. In contrast, my own theory is process oriented and, consequently, words like " operation " have a different meaning. Any strategy is made up of operations which (in my sense) are akin to Miller, Gallanter and Pribram's (1960) TOTE units, and which are assembled into hierarchical or interactive structures. Such a structure is a possible strategy and, when executed, it gives rise to a *process*. The most elementary operations are thus of the same type and the subroutines made up of them differ from one another in respect to context; *i.e.* their differences rest upon the operations or processes upon which they depend.

In general, ability tests may be expected to sample the efficiency of commonly occurring subroutines. But any " operation " (in my sense) entails entries, in many of Guilford's cells; indeed, it involves most if not all of Guilford's operations. The multiple reference is neither surprising nor disturbing but it does highlight the question of whether Guilford's taxonomy is appropriate for a process model; a question which is undecided at the moment. It is also pertinent to remark that the currently available ability tests are far from optimal devices for sampling the basic competence data when a process model is in mind; for example, there is no test that distinguishes between people's ability to build up association-discrimination processes and their ability to construct rule-like procedures (which is an outstanding distinction from a process oriented point of view).

Matching

Suppose that a task is given. Several different performance strategies, $a_1, a_2 \ldots$ (members of a set A), are generally available in the sense that each one of them has been used by some subject. In the simplest case, there is a unique learning strategy, b, (one member of a set B) which is applicable in acquiring or inculcating a performance strategy; hence, picking out a particular performance strategy a_i isolates one learning strategy b_i (however, a one-to-one correspondence may not exist in general, *i.e.* a_i may point to a subset $B_i = b_{i1}, b_{i2}, \ldots$ of learning strategies). Assuming the simplest case, let $Z(a_i, b_i)$ be the set of commonly occurring subroutines involved in the execution of a_i, b_i and let C be a competence profile which evaluates each of many possible subroutines, for a given individual, S. Considering only those operations in $Z(a_i, b_i)$, form the product of their evaluations. The degree of matching between a_i, b_i and individual S is simply this product.

It is not difficult to erect much more refined indices of matching but, however elegant, these are unlikely to prove necessary. In practice, there are relatively few strategies to be considered and the majority of these are grossly mismatched to the individual (that is, relative to one or two outstandingly well matched strategies).

Some difficulties

In free learning conditions most subjects are bad at selecting matched strategies. As a result, they learn slowly, if at all. To some extent this may be due to ignorance of the strategies available and it is certainly true that the imposition of *any* well defined strategy (for example, via a teaching program) generally enhances learning efficiency.

But, on the other side of the coin, students commonly bring preconceived notions to bear upon the process of learning and these notions are the germs of strategies even if they cannot be verbalised as plans. Generally speaking, any imposed strategy is in competition with strategies that already exist. Hence, in a teaching system, it is essential to discover what the competing strategies are by allowing the subject to assert them. This is one reason why the system should be a conversational system in which the subject is encouraged to talk about the learning process.

Moreover, even if the student is fully aware of the strategic possibilities (for example, as a result of a preliminary discussion), he is still prone to adopt the " wrong " strategy. An important factor in the decision process is undoubtedly the student's misperception of his own characteristics. On the whole, students are unaware of their competence and the situation is improved if appropriate competence evaluating information is provided. But misperception is not the only factor. When given the requisite information, individuals are still apt to disregard it, or (putting the matter differently) they need to accumulate a large amount of evidence before they will autonomously change their minds and adopt a more appropriate strategy than the one they chose originally. This tendency is commonly manifest and I shall call it " Cognitive Fixity " since, in many ways, it resembles Festinger's (1959) " Cognitive Dissonance." To minimise cognitive fixity, it is thus not only necessary to provide competence evaluations but also to actively dissuade the subject from pursuing misguided lines of action. This is the other reason why a conversational design is often mandatory.

There has been a lot of cognitive fixity over writing this paper, for instance. One starts off with a goal of sorts; the paper must satisfy limits of length and comprehensibility; it must put across certain salient ideas. The goal generates a strategy; the paper has a general form and its parts are tackled in a given order. The fixity occurred as follows: At one stage in writing the paper, I invested a great deal of effort in a section developing the theoretical underpinning of the argument. This, of course, constrained the form and content of the rest of the paper and made it virtually impossible to present an understandable case. Nevertheless, the effort *had* been spent and I liked the style of the section. In fact, the paper got nowhere (and was probably unwritable in principle) until I eventually collected sufficient evidence to make me expurgate the offending section. Moreover, a sort of trapping state is involved. The longer that the inappropriate strategy persists (in this instance the strategy engendered by the theoretical section) the more it colours the rest of the structure and the more difficult it becomes to dislodge. Finally, cognitive fixity is operative even though the subject knows all about it; after all, I was writing a paper about cognitive fixity when I fell into these snares. The fact is, human beings are not very good at self-observation or self-control and cognitive fixity (which is perhaps the major obstacle in the path of effective learning) can only be reduced by an outside influence.

2. SPECIFIC INVESTIGATIONS

Due to the complexity of real life learning situations, it is quite difficult to glean individualised data of a type that will illuminate the issues discussed in the first part of this paper. The learning strategies germane to geography, history or chemistry may extend over days or even weeks and regularities are obscured by interruption and extraneous activity. More definitive results are likely to stem from laboratory studies. On the other hand, conventional learning experiments do not allow for strategic diversity and a special choice of task is called for.

Form of the experimental situation

Problem solving tasks satisfying the following conditions have proved especially useful:

(1) The task is learnable in a single session, albeit quite a lengthy session (5–7 hours is perfectly practicable).

(2) The problems and subproblems belong to well defined classes so that the experimenter and the subject are in agreement regarding which class a problem belongs to.

(3) Although the subject is given the goal of learning to solve full problems (of the main class) these should be far too difficult for the novice to tackle *in toto*. Thus, any subject is forced to adopt a strategy of partitioning the task by learning to deal with subproblem classes one after another (eventually becoming proficient with respect to the full problems).

(4) Problem solution is rapid so that the experimenter can present the subject with representative sequences of problems drawn from each class.

(5) It is possible to evaluate the subject's performance and to offer him indices of success and goal approximation.

(6) The learning strategy (which any subject is forced to adopt, as in (3) above) can be externalised as a stretch of behaviour. It is convenient to concentrate upon the attention directing aspect of a learning strategy and to regard the strategy as externalised in so far as the subject attends to a sequence of subproblem classes, terminating in the class of full problems.

(7) The subject can be given reasons for externalising a process which is, from his point of view, more conveniently carried out in his head (when, of course, it is hidden from the experimenter). For example, the subject may be asked to physically select a class of subproblems by pushing buttons on a console as a result of which a sequence of problems drawn from this class is presented to him. If so, we must remember that the subject could partition the full problems mentally and solve part of each full problem in his head. To induce him to make objectively detectable selections in a veridical fashion (rather than the capricious manner he might adopt following a mere command) it is possible to use expedients such as:

(A) The subject agrees to maintain at least a certain average score over and above agreeing to aim for the educational goal. A score is computed with respect to the selected class only (note, if the novice selected the full problems the score would be so low that the subject could not keep his agreement).

(B) Knowledge of results is provided in respect to the selected class (note, this gives the student detailed as against macroscopic information).

(C) Facilities, such as evaluative data, are provided in the framework of the classes so far selected.

Techniques like (A), (B) and (C) have been called co-operative externalisation techniques or CETS (Pask, 1968b, 1969b, 1965a and b).

(8) It is possible to determine the subject's competence by tests that are relevant to the task. Usually behavioural tests are called for; paper and pencil ability tests could be used but they are insufficiently specific and are inconvenient for on-line administration.

(9) It is possible to ascertain the subject's performance strategy. Once again, behavioural measurements are preferred.

(10) The investigation is greatly simplified if one learning strategy is used to build up just one performance strategy.

(11) The task is related to a useful category of real life tasks.

Free learning experiments

Experiments have been carried out in a situation that approximates conditions (1)–(11), and which may be viewed as a microcosm embodying certain aspects of real life relation learning. The task employed was an elaboration of a transformation or signal translation task considered in a previous paper in this journal (Pask and Lewis, 1967) and it has been used extensively in studies of adaptive teaching systems. A full account of the experiments is given in Pask and Lewis (1968), Pask (1969c) and Pask and Scott (1969).

In the full problem situation (which must ultimately be mastered) the subject is presented with a sequence of four variable visual signals and must solve each problem by making an appropriately coded four component response. Calling the signal variables A, B, C and D, the full problems belong to a class named (ABCD), *i.e.* its members present all of the variables at once. Under the temporal constraints imposed upon the task, a novice is quite unable to learn how to deal with problems in (ABCD) and is thus impelled to direct his attention to subproblem classes of the form (A), (B), ... (AB), (BC), ... (ABC), (ABD), ... (there being 15 classes in all). The experiment is fully automated and the subject is asked to externalise his attention directing strategy at the end of each block of trials (each sequence of problems) by keying into his console the name of the subproblem class which he will consider during the subsequent block. This selection determines the subproblem class from which stimuli (designating the problem) are actually drawn. A CET involving the provision of scores, evaluations and knowledge of results is used to secure reliable externalisation.* In these conditions a learning strategy is manifest.

1. As a sequence of subproblem class selections *and*
2. Through information obtained, on subsequent *interrogation*, about how these selections depended upon the evaluation and scores.

Preliminary studies revealed the existence of four types of learning strategy.

A. Build up in a sequence; typically (A) → (B) → (AB) → (C) → (ABC) → (D) → (ABCD).

B. Explore all subproblem classes in turn.

C. Group problems into increasingly large units; typically (A) → (B) → (AB) → (C) → (D) → (CD) ⇄ (AB) → (ABCD).

D. Try to do it all at once; typically (A) → (B) → (C) → (D) → (ABCD).

One variant, C*, of the Type C

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* In fact, the CET was quite elaborate and depended upon a method for committing the subject to a certain level of performance. On entering a block (say (AB) or (ABC)) the subject knows that he cannot exit until he has responded correctly on at least one occasion to each stimulus in the sequence. Of course, he need not respond correctly on the *first* presentation but the block sequence is continued until

strategy, is noted in the source paper, but will not be discussed.

Of these possibilities, the performance strategy that goes with learning strategy Type D leads to triviality in so far as the subject who uses it is failing to solve the entire problem. In contrast, he deals, at his leisure, with as many separate items as there are stimulus variables (it is doubtful whether, in this case, his behaviour is a problem solving behaviour). Hence, a time constraint was imposed to prohibit the offending performance strategy. In fact, the time allowed for solving each problem was separately adjusted for each individual (in a preliminary adaptively controlled session), so that no more than a pair of elementary operations could be carried out at any one trial. As a result, subjects were *told* and *knew* that learning strategy D was bound to be abortive. Moreover, they *experienced* this fact since, before the main experiment (but after the adaptive period) each subject had practice in learning the skill with a different coding rule in force.

Two types of competence were observed as response processes, manifest in regular patterns amongst latencies of the several components of the complex response: (a) a serial competence (introduction) which, at the microscopic level, is called *stringing* (of response producing operations); (b) a holistic competence, interpreted as a *grouping* of operations.

The main findings of the free learning experiments were that though a few subjects learned the skill successfully (in 400 trials or so) the great majority did not, (some taking 750–1,000 trials and a few hardly learning it at all). Those who failed did so for quite definite reasons.

1. The subject tries to use strategy D, even though he knows that it cannot succeed. The lure of getting straight to the goal is remarkably seductive. Eventually, strategy D is abandoned in favour of some other plan and the student takes about as long to learn the skill as he would have done starting out this way.
2. Subjects who are good at stringing but bad at grouping, try to use strategy C (which is fitted to grouping). Their learning is retarded and occasionally they are forced to change strategy.
3. Subjects who are good at grouping but bad at stringing, try to use strategy A (which is adapted to stringing). Their learning is retarded and occasionally they are forced to change strategy.
4. Subjects adopt strategy B. In most cases, it would be more accurate to say that these subjects have no global strategy. (Certain exceptions exist. In later experiments where pre-experimental and post-experimental protocols were taken, one subject did express the intention of exploring, and produced Type B selections. But most of the apparent explorers turn out to be people who are in doubt about what to do. This contention is supported by subjective confidence estimates over the set of subproblem classes, which were obtained after each block.)

In all, 26 subjects have been run in the free learning situation. Ten of these

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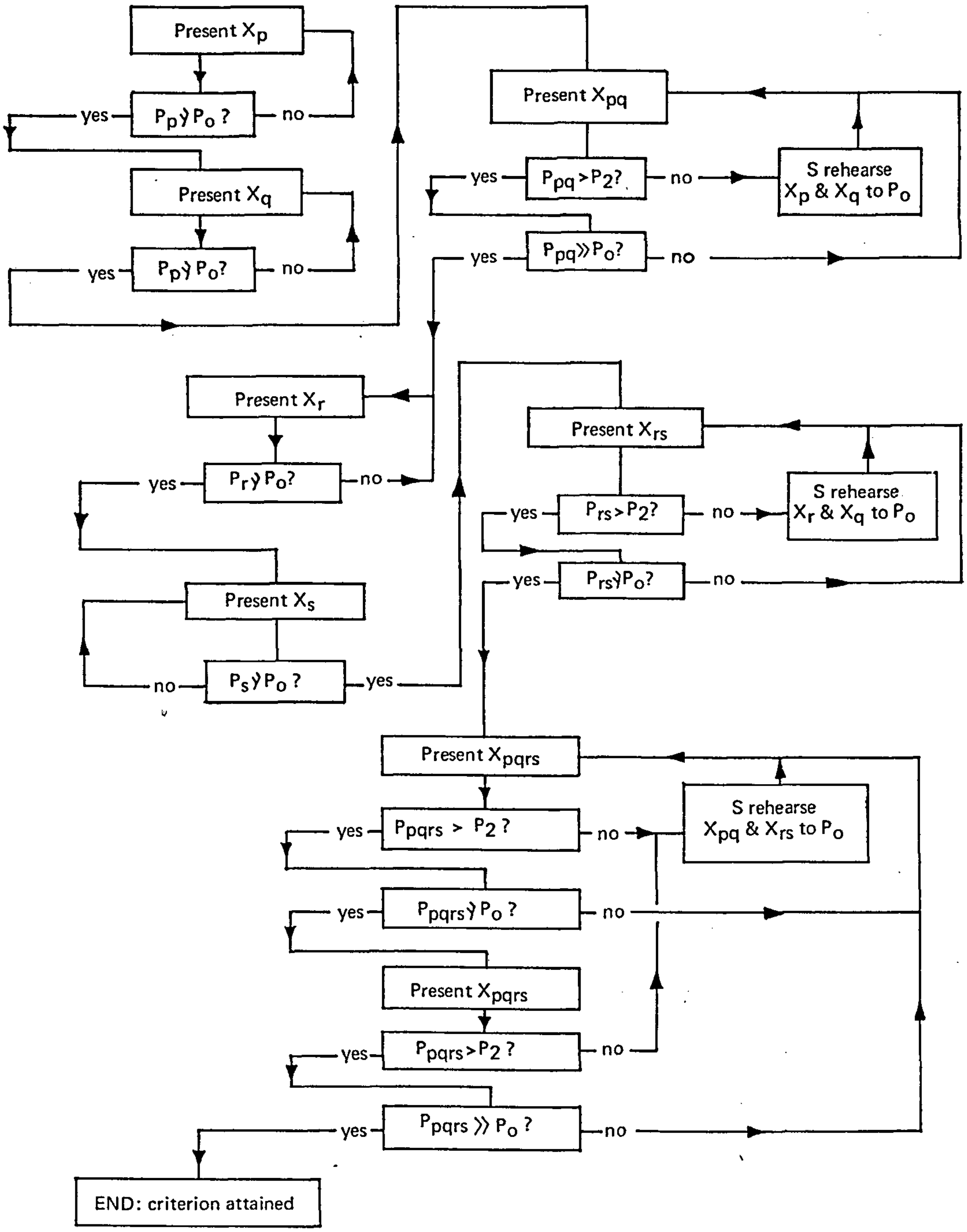
this criterion is satisfied. The score is the number of "first presentation correct responses" (divided by the number of different stimuli). From the number of repetitions or guesses we derive a direct measure of the subject's uncertainty.

FIGURE 1

FLOW CHART FOR THE ADAPTIVE SYSTEM BASED ON TYPE C. STRATEGY



Explanation: The X_i are the subproblem classes. The subscript values (p, q, r and s) correspond to the signal variables, A, B, C and D in the order that they are *first selected.* In the adaptive system, the machine makes all selections and is set so that p = A, q = B, r = C and s = D. Thus, *e.g.* $X_{pqr} = (ABC)$.

The P_i are scores of first presentation correct responses to the signals in the subproblem class X_i.

P_0 and P_2 are, respectively, the upper and lower thresholds, where $P_0 = 75$ per cent. and $P_2 = 25$ per cent first presentation correct responses.

All commands are to the adaptive machine except for those prefaced by "S" which are commands to the subject.

were run in conditions which are strictly comparable with those of subsequent experiments and for this subgroup the mean number of trials to criterion was 574·5 SD = 153.

Adaptive instruction

The most obvious way to remedy some of these defects is to impose a teaching strategy upon the subject. Since there is great individual variation in how long it takes a subject to achieve criterial proficiency, teaching must be a score sensitive procedure mediated by an adaptive system. However, the machine is designed on the basis of just one strategy and *it* (rather than the subject) makes all subproblem class selections.

Now, learning in the signal translation skill has been extensively computer simulated and there are good grounds for supposing that strategy C is logically the best. It is not the best strategy for each individual, of course; Type A would be better for someone with a proclivity for stringing. But it is as good as any other *single* alternative, and the machine was thus based upon a Type C strategy. The flow chart of the adaptive system is shown in Figure 1. The subject is advanced to the next selection in the strategy if his score exceeds an upper threshold, "sent back" if his score is less than a lower threshold, and "left where he is" if his score lies between these limits.

The results obtained from the single strategy adaptive experiments are quite unequivocal. This type of instruction is faster than free learning. (Mean trials to criteria = 463 SD = 167, N = 10) and the difference

Learning Rate (Adaptive) > Learning Rate (Free Learning)

is significant at the 0·1 per cent. level. We did, of course, check that the difference could not be attributed to the initial setting of the time allowed for making a response. In any case the same result is obtained in terms of ratio or saving scores computed for each individual as a comparison between preliminary run (free learning) and main run (adaptive) in the same experiment. However, the "good" adaptive subjects who really account for this marked difference are precisely those who, on the basis of continuously recorded latency patterns, do show an ability for "grouping." The others do not fare so well.

Conversational instruction

If we really believe in the argument put forward in the first part of the paper, then instruction should be *conversational.* So far as possible, the subject should be allowed to make his own selections, as in the free learning condition, contingent only upon achieving a reasonable level of proficiency with respect to each subproblem class. At some stage, however, his attention directing behaviour will commit him to a strategy (for example, having selected (A) → (B) → (AB) → (C) he may either adopt Type A and go on to (ABC) or Type C and go on to (D) → (DC)). At this point the strategic alternatives should be exhibited so that the student can opt for one of them. His choice should now be monitored by the teaching system, which assesses his competence with respect to each strategy (by carrying out a " look ahead " test and determining his disposition to " group " or to " string "). If the subject's choice is appropriate and the strategy is *matched*, then he should be allowed to proceed as he wishes contingent only upon satisfying behavioural criteria related to grouping and stringing latency patterns (not just to overall score, which at this stage is no longer the most relevant variable). On the other hand, if the subject has selected a *mismatched* strategy, he should be informed of this fact and diverted onto a *matched* strategy (always being allowed to override the system on some subsequent occasion if he can, at that point, pass the " look ahead " test).

The design of a conversational system is based on a class of strategies (Type A, B and C), not just one strategy. Its flow chart is shown in Figure 2 and allows for all sorts of remission and recycling which may complicate the picture sketched out above.

The results of the experiments demonstrate a clear advantage in favour of the conversational system:

Mean Trials to Criterion = 220 SD = 40·6, N = 10

The difference

Learning Rate (Conversational) > Learning Rate (Adaptive System)

is significant at the 0·1 per cent. level (the same precautions being taken with respect to time allowed and ratio scores).

Although the Tybe B (exploratory) strategy was offered as an option, no conversational subject chose it and the confidence estimation data indicates that this was because no subject had any doubt about what he ought to do (though all subjects had the liberty to choose selections). By definition, all strategies were matched to the subject's competence so, not surprisingly, " grouping " subjects followed a Type C plan and " stringing " subjects a Type A.

The most dramatic difference between the free learning and the conversational subjects is in the elimination of cognitive fixity, especially with respect to the Type D strategy. On average, the free learning subjects spent 39·8 per cent. of their subproblem selections rehearsing problems in class (ABCD) and most of the trials were abortive as indicated by the high uncertainty over these blocks (computed from the " number of guesses " data provided by the CET). This is by far the largest percentage of selections for any problem class; the next largest is (ABC) with 15·6 per cent. In contrast, the conservational subjects spent only 25·2 per cent. of their selections rehearsing problems from class (ABCD) and they experienced relatively little uncertainty. This percentage is *not* the highest; more selections were spent rehearsing (AB) at 26·1 per cent. Hence, the whole pattern of learning in the conversational system differs markedly from free learning. In particular, the rate of

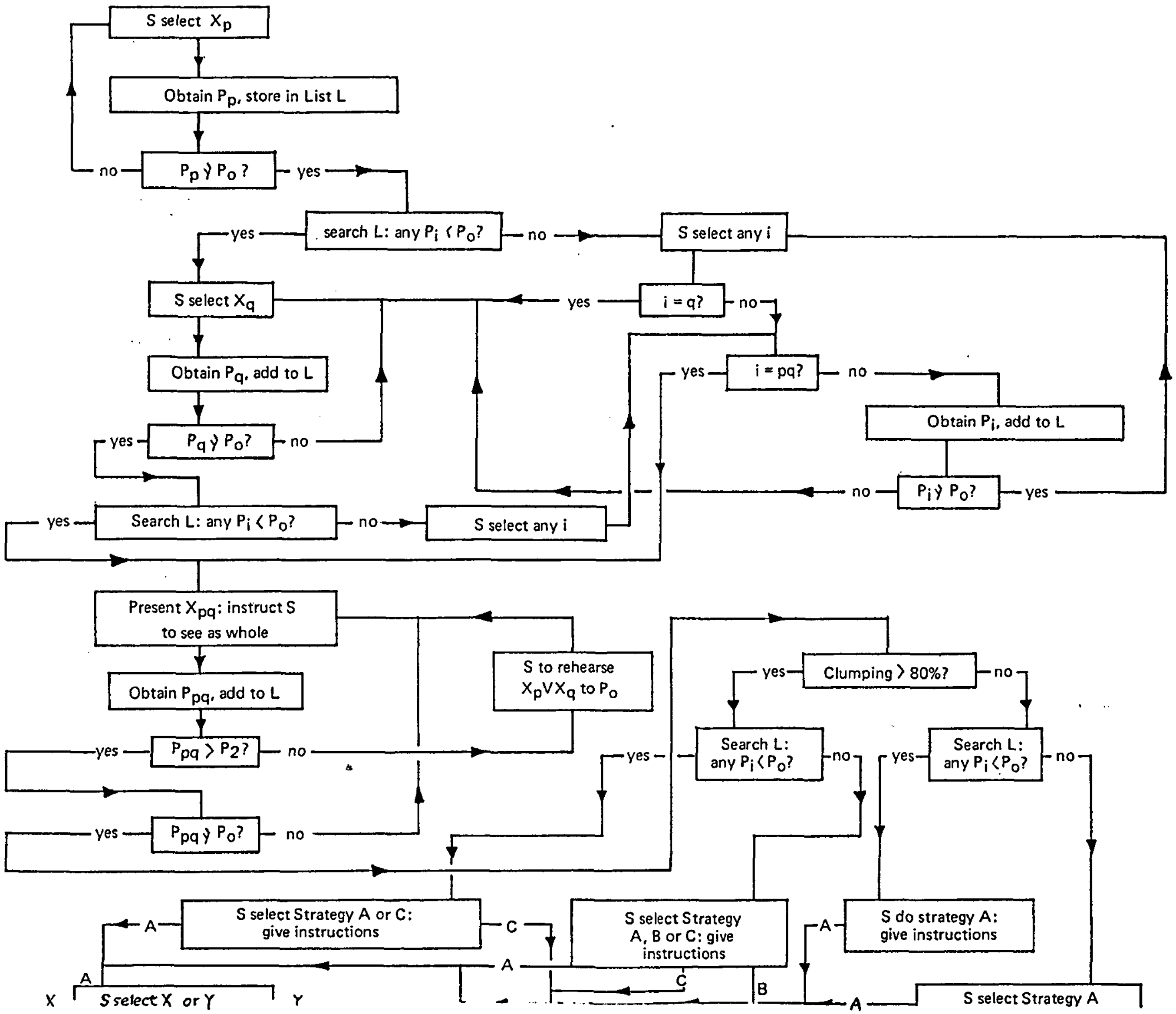
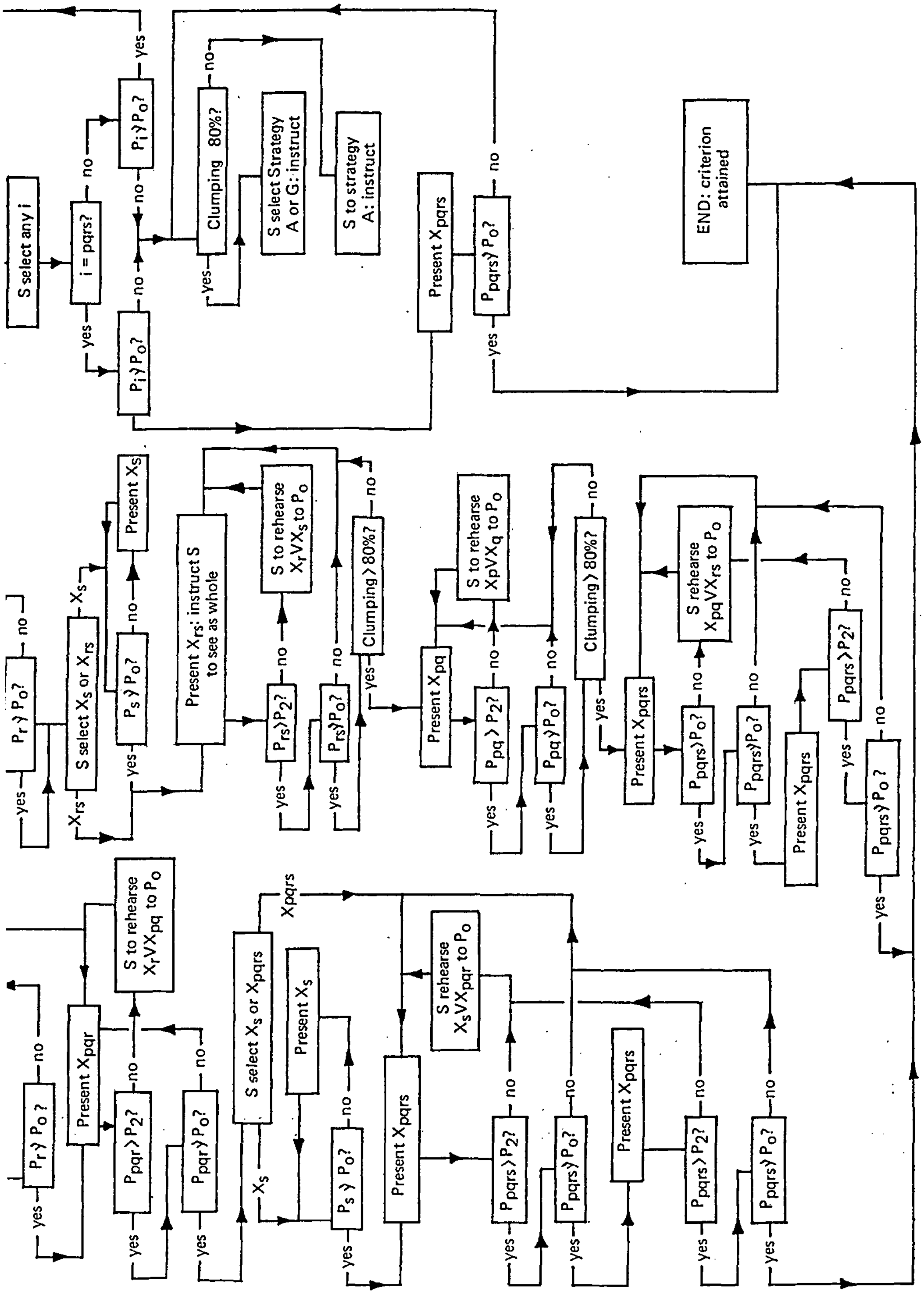

S select X_p
Obtain P_p, store in List L
no
$P_p \geq P_o$?
yes
yes
search L: any $P_i < P_o$?
no
S select any i
S select X_q
yes
i = q?
no
Obtain P_q, add to L
yes
i = pq?
no
yes
$P_q \geq P_o$?
no
Obtain P_i, add to L
no
$P_i \geq P_o$?
yes
yes
Search L: any $P_i < P_o$?
no
S select any i
Present X_{pq}: instruct S to see as whole
S to rehearse $X_p V X_q$ to P_o
yes
Clumping > 80%?
no
Obtain P_{pq}, add to L
yes
$P_{pq} > P2$?
no
yes
Search L: any $P_i < P_o$?
no
yes
Search L: any $P_i < P_o$?
no
yes
$P_{pq} \geq P_o$?
no
A
S select Strategy A or C: give instructions
C
S select Strategy A, B or C: give instructions
A
S do strategy A: give instructions
A
A
C
B
X
S select X or Y
Y
A
S select Strategy A

FIGURE 2
FLOW CHART FOR THE CONVERSATIONAL SYSTEM

Explanation: As for Figure 1 with one addition: the test of a subject's ability to make grouped responses ("clumps") is represented by the test box "Clumps 80 per cent," *i.e.* to pass the test at least 80 per cent, of a subject's "first presentation" responses must be correct *and* grouped.



decrease of the student's relevant uncertainty is faster and smoother.

General application

These results are definite. To some extent their sharpness is due to the miniscule character of the learning situation, but I believe the experiments mirror some important aspects of most learning processes and that the results support the pre-requisites for effective education which were proposed in the introduction. To summarise the matter, teaching systems ought to be conversational in form and so devised that strategies are matched to individual competence.

This conclusion is peculiarly relevant to computer assisted instruction where the facilities for conversational interaction are present if the programmer cares to use them and there are some CAI systems (notably Kopstein and Seidel's (1969) IMPACT system) which embody principles similar to those in Figure 2. But even in the absence of a computer, educational techniques and testing procedures can and should be organised in a way that approximates a " matched " and " conversational " situation.

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